Wire-Probing Technique to Revascularize Subacute or Chronic Internal Carotid Artery Occlusion

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Key words: carotid occlusion, endovascular, revascularization

Summary

During endovascular revascularization of subacute and chronic occlusion of the cervical internal carotid artery (ICA) it may be difficult to penetrate the lesion. Selecting the appropriate "true lumen", a remnant of what had been the arterial lumen, at the initial step may facilitate the procedure. Because plaque at the carotid bifurcation is known to propagate from the posterior wall, a gateway to this "true lumen" should exist in the anterior side of the occluded stump. This hypothesis was studied retrospectively in our series of revascularizing ICA subacute and chronic occlusion.

Eleven patients underwent endovascular revascularization for symptomatic cervical ICA occlusion. Procedures were performed by initially penetrating the occluded stump with a guidewire, followed by supporting catheter advancement through the occluded segment to secure the distal normal arterial lumen. Cases were analyzed with regard to the location of initial guidewire penetration.

Eight patients underwent successful revascularization. In five cases, the entry point to the occluded stump was located at the anterior side, and in three, at the posterior side. Two posterior stump penetration cases were met with resistance in guidewire advancement, whereas penetration was smooth in the anterior cases. In addition, two posterior stump penetration cases resulted in contrast stasis in the posterior ICA wall.

In our series of revascularizing cervical ICA subacute and chronic occlusion, initially targeting the anterior side of the occluded stump resulted in favorable results. This may be the result of selecting the "true lumen" at the beginning of the procedure.

Introduction

Advancements in endovascular technology and technique have enabled endovascular revascularization of chronically occluded vessels such as subclavian, coronary and iliac arteries [1-3]. More recently, a few reports demonstrated successful recanalization of chronically occluded carotid arteries with acceptable feasibility and safety [4-10]. However, this procedure can be difficult because there is no visualization of the route to guide the devices through the occluded segment. Theoretically, devices should be advanced through the "true lumen", a putative space that had been the arterial lumen for the best result. Initial access to this "true lumen" would be the critical first step in achieving this.

Plaque at the carotid bifurcation is known to propagate at the posterior wall and extend anteriorly [11,12]. Based on this knowledge, we hypothesized that by targeting the anterior side of the stump at the beginning of the procedure, we would be able to enter the "true lumen". We retrospectively reviewed our experience to revascularize subacute and chronic occlusion of internal carotid artery (ICA) with focus given on the initial access to the occluded stump.

Materials and Methods

All patients who underwent endovascular revascularization for cervical ICA subacute and chronic occlusion between August 2006 and January 2010 at our institution were included in this study. The study was approved by the Institutional Review Board and consent was obtained from all patients participating in the study. Patients' presentation was categorized into transient ischemic attack (TIA), minor, and moderate stroke. TIA was defined as transient focal neurological deficit resolving within 24 hours without documented ischemic change on cerebral magnetic resonance imaging (MRI). Minor stroke was defined as focal neurological deficit resolving within seven days with documented ischemic change on MRI. Moderate stroke was defined as non-disabling permanent focal neurological deficit with ischemic change on MRI. Occlusion of the cervical ICA was initially diagnosed by magnetic resonance angiography (MRA) at the time of onset of symptoms, which was then confirmed by conventional cerebral angiography. The period between angiographically confirmed ICA occlusion date and treatment was defined as the occlusion period. An occlusion period of two to four weeks was defined as subacute, and more than four weeks as chronic. All patients had a recurrent non embolic ischemic event in the ipsilateral cerebral hemisphere or retina after the index stroke while on antiplatelet therapy. A non embolic ischemic event was defined as amaurosis fugax, TIA, or small DWI high intensity lesion not exceeding 5 mm in diameter. Single photon emission computed tomography (SPECT) using technetium Tc99m ethyl cysteinate dimmer with acetazolamide vasodilatory challenge was obtained in all patients undergoing the procedure. Patients were indicated for endovascular revascularization on the basis of severe cerebral blood flow (CBF) compromise in the affected hemisphere demonstrated by the SPECT study. Namely, <80% resting CBF compared with the contralateral hemisphere and <10% CBF increase in the affected hemisphere with acetazolamide challenge. All patients were pretreated with dual antiplatelet therapy, either by combination of 100 mg aspirin and 200 mg cilostazol daily, or 100 mg aspirin and 75 mg clopidogrel daily.

A transfemoral or a transbrachial approach was used to access the lesion. After establishment of initial vascular access, 100 mg/kg of heparin was given to achieve an activated clotting time of 250-300 seconds. A 9-Fr Patlive balloon guiding catheter (Terumo Clinical Supply, Gifu, Japan) or a 6-Fr Shuttle sheath (Cook, Bloomington, IN, USA) was advanced to the common carotid artery proximal to the occluded stump. To initially penetrate the occluded segment at the stump, a 0.035-inch Radifocus guidewire (Terumo, Tokyo, Japan) was typically used. After then, various guidewires including 0.038-inch Radifocus (Terumo, Tokyo, Japan), 0.012-inch and 0.016-inch GT (Terumo, Tokyo, Japan), 0.010-inch Runthrough (Terumo, Tokyo, Japan), 0.014-inch Astato (St. Jude Medical Japan, Tokyo, Japan), and 0.014-inch Fielder (Asahi Intecc, Nagoya, Japan) were used to penetrate the occluded ICA. A 4-Fr Tempo 4 catheter (Cordis, Miami, FL, USA) was usually added coaxially to provide extra backup support. To prevent distal cerebral vessel emboli, proximal protection, distal protection, or a combination of these was used. The technique for proximal protection has been previously described[13]. Once the distal ICA lumen was secured, distal protection was applied in all cases using GuardWire (Medtronic, Minneapolis, MN, USA). Balloon angioplasty was performed successively from distal to proximal ICA, followed by self-expanding (Wallstent RP, Boston Scientific, Natick MA, USA, or Precise, Cordis, Miami, FL, USA) stent placement at the most stenotic portion of the occlusion, usually the common carotid bifurcation. Additional stents were deployed at the intracranial ICA depending on angiographic findings such as dissection or remaining stenosis (Multi-Link Vision, Abbott Vascular, Santa Clara, CA, USA). All patients were placed on argatroban infusion for 48 hours post-stenting, and double antiplatelet therapy was continued.

Medical and radiographic records were retrospectively analyzed for details of the patient characteristics and procedures. Attention was focused on the course of the guidewire when initially penetrating the occluded stump. The course of the guidewire was described as "anterior" or "posterior" when penetration occurred at the anterior or posterior part of the stump, respectively. Procedures were divided into anterior and posterior penetration groups to compare technical success rate and difficulty in penetrating the occluded ICA segment. Technical success was defined as completion of successful revascularization. Easy guidewire advancement was defined as meeting all the following criteria: 1) Fewer than two attempts to advance the guidewire to the distal ICA stump (not necessarily securing the distal ICA lumen). 2) Application of fewer than three guidewires. 3) No forceful guidewire manipulation. On the other hand, difficult guidewire advancement was defined as meeting either of the following criteria: 1) More than three attempts needed to reach the distal ICA stump. 2) Application of more than four different guidewires. 3) Use of forceful pressure and/or torque to the guidewire.

Results

Patient characteristics are listed in Table 1. Eleven patients underwent endovascular revascularization between the study period, resulting in eight successful procedures. All of the patients were male, ages ranging between 50 and 78 years. One patient presented with TIA, eight with minor stroke, and two with moderate stroke. Angiographic study demonstrated occlusion of the cervical ICA at the origin as shown in Figures 1A and 2A in five cases, and 1 to 2 cm distal to the origin as represented in Figure 3A in six cases. Retrograde ICA filling from external carotid artery collaterals was seen in all cases as shown in Table 1. Occlusion period ranged from three weeks to 15 months. Aspirin and cilostazol were given in four patients, aspirin and clopidogrel in four, clopidogrel and cilostazole in two, and ticlopidine and cilostazole in one.

Procedure details are shown in Table 2. Seven occluded segments were penetrated from the anterior part of the stump and four from the posterior. Five cases of anterior penetration (5/7, 71%) and three cases of posterior (3/4, 75%) resulted in successful revascularization. Both anterior and posterior penetration groups did not differ in the technical success rate (71% versus 75%). However, lesions penetrated from the anterior part of the stump met with less difficulty in advancing guidewires through the occluded segment compared to posterior group. Only one case in the anterior penetration group (1/7, 14%) was met with difficulty, whereas in the posterior penetration group, that number was three (3/4, 75%). Three cases in posterior penetration resulted contrast stasis in the posterior wall of the ICA (Figures 2C,D, 3C,D).

All patients underwent neurological examinations immediately after intervention and at discharge. An MRI study within seven days post procedure was also obtained in all patients. No new neurological deficits occurred due to the procedure. However, one to nine new DWI high intensity ischemic lesions, size ranging from 3 to 14 mm, were observed in 64% (7/11) of the patients.

Table 1 **Patient characteristics.**

Pt.	Age	Sex	Presentation	Occlusion period	Angiographic Occusion site	Retrograde filling	Antiplatelets
1	68	M	Minor	3 wks	1 cm distal	High cervical ICA	ASA/cilostazol
2	78	M	TIA	6 mos	Origin	C5	ASA/cilostazol
3	70	M	Moderate	7 mos	Origin	C4	ASA/cilostazol
4	67	M	Minor	2 mos	1 cm distal	C5	ASA/clopidogrel
5	50	M	Minor	2 mos	Origin	C5	ASA/cilostazol
6	57	M	Minor	15 mos	Origin	C3	ticlopidine/cilostazol
7	74	M	Minor	4 mos	1 cm distal	C4	ASA/clopidogrel
8	72	M	Minor	6 mos	1 cm distal	Petrous ICA	ASA/clopidogrel
9	54	M	Moderate	2 mos	2 cm distal	C4	ASA/clopidogrel
10	60	M	Minor	2 mos	Origin	C5	clopidogrel/cilostazol
11	53	M	Minor	1 mo	2 cm distal	C4	clopidogrel/cilostazol

Pt = patient; M = male; TIA = transient ischemic attack; wks = weeks; mos = months; ASA = aspirin.

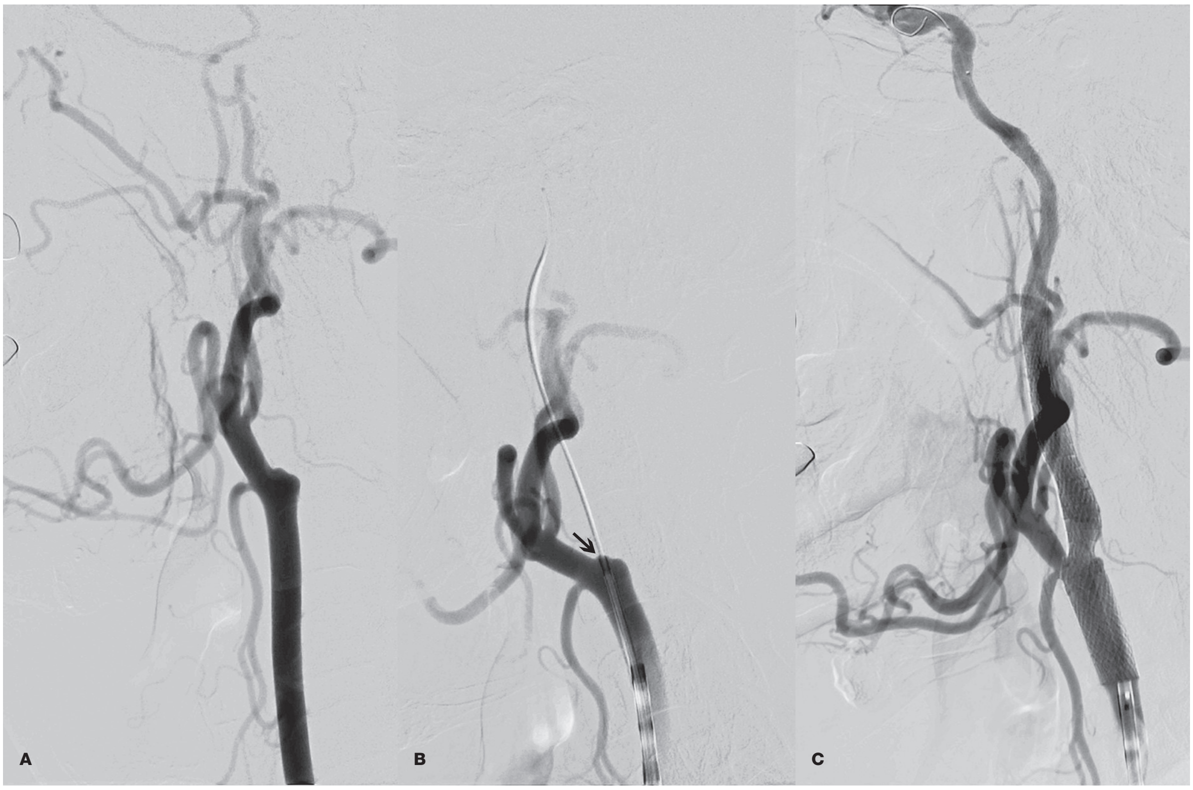

Figure 1 A) Right common carotid angiogram in lateral view demonstrates occlusion of the internal carotid artery (ICA) at the origin. B) Guidewire penetration from the anterior side of the occluded stump (arrow) results in successful advancement of the guidewire through the occluded segment. C, Angiogram following 2 × stent deployment demonstrates successful revascularization of the occluded ICA.

Illustrative Cases

Patient 5

This 50-year-old male patient presented with left upper extremity weakness and a frontal lobe infarction, documented by linear elevated intensity in the right premotor cortex on diffusion-weighted imaging (DWI). Cervical MRA demonstrated right ICA occlusion, which was confirmed by angiographic study (Figure 1A). Retrograde right ICA opacification was seen to the C5 level from external carotid artery collaterals (not shown). The patient underwent endovascular revascularization two months after the initial diagnosis after pretreatment with 100 mg aspirin and 200 mg cilostazol daily. A 9-Fr Patlive balloon catheter was placed in the right common carotid artery. With the support of a 4-Fr Tempo catheter, the occluded stump was penetrated from the anterior side with a 0.035 Radifocus guidewire (Figure 1B). After securing the distal true ICA lumen, a GuardWire was introduced to provide distal protection. Angioplasty was performed with a 4.0 × 30 mm Gateway balloon (Boston Scientific, Natick, MA, USA) from distal to proximal successively, then two Precise stents, 9 × 40 mm distally, and 10 × 40 mm proximally, were overlapped at the carotid bifurcation (Figure 1C).

Patient 3

A 70-year-old male patient presented with a change in affection. Workup cerebral MRI revealed right parietal lobe infarction in two cortical branch areas. Angiographic study demonstrated occlusion of the right ICA at the origin with retrograde ICA filling to the C4 level (Figure 2A). The patient underwent endovascular revascularization seven months after the initial event, after pretreatment with 100 mg aspirin and 200 mg cilostazol daily. A 9-Fr Patlive balloon catheter was placed in the right common carotid artery. Under proximal protection, the occluded stump was penetrated from the poste-

Table 2 **Procedure details.**

Pt.	Initial Penetration	Revascularization	Wire advancement	Guidewire	Forceful guidewire manipulation	Reason for failed revascularization
1	Anterior	Yes	Easy	0.035 Radifocus	No	
2	Anterior	Yes	Easy	0.035 Radifocus 0.010 Runthrough 0.014 Synchro	No	
3	Posterior	Yes Posterior contrast stasis	Difficult	0.035 Radifocus 0.016 GT 0.010 Runthrough	Yes	
4	Posterior	No Posterior contrast stasis	Difficult	0.035 Radifocus 0.010 Runthrough × 2 0.016 GT	Yes	Failed distal ICA stump penetration
5	Anterior	Yes	Easy	0.035 Radifocus	No	
6	Anterior	No	Easy	0.035 Radifocus 0.010 Runthrough	No	Failed distal ICA stump penetration
7	Anterior	No	Difficult	0.035 Radifocus 0.038 Radifocus 0.014 Treasure 0.014 Astato	Yes	Failed cervical ICA penetration
8	Posterior	Yes	Difficult	0.035 Radifocus 0.010 Runthrough 0.012 GT 0.014 Déjà vu 0.014 Treasure	Yes	
9	Anterior	Yes	Easy	0.035 Radifocus 0.014 Fielder	No	
10	Posterior	Yes Posterior contrast stasis	Easy	0.035 Radifocus 0.014 Fielder	No	
11	Anterior	Yes	Easy	0.035 Radifocus 0.014 Fielder 0.012 GT	No	

rior side with a 0.016 GT microguidewire (Terumo, Tokyo, Japan), supported by an Echelon 14 microcatheter (ev3, Irvine, CA, USA) (Figure 2B). With difficulty, the microguidewire and microcatheter was advanced to the distal ICA true arterial lumen at the C4 portion. Then, the system was exchanged to a GuardWire to provide distal protection. At this point, stasis of contrast was noted at the posterior wall of the ICA (Figure 2C). This lumen showed an identical curve with the course of the GT microguidewire that initially penetrated this segment (Figure 2B). Additionally, the GuardWire was located anterior to the initially penetrated lumen. Angioplasty with 4.0 × 30 mm Gateway balloon and stenting with overlapping 8 × 40 mm Precise and 10 × 20 mm Wallstent stents was then performed. Post-stenting angiogram shows persistent stasis of contrast in the posterior wall of the ICA outside the stent (Figure 2D).

Patient 4

A 67-year-old male patient presented with mild left upper extremity weakness. Workup MRI revealed four areas of cerebral infarction measuring approximately 1 cm each in the right parietal and frontal lobes. Angiographic study demonstrated occlusion of the right ICA just

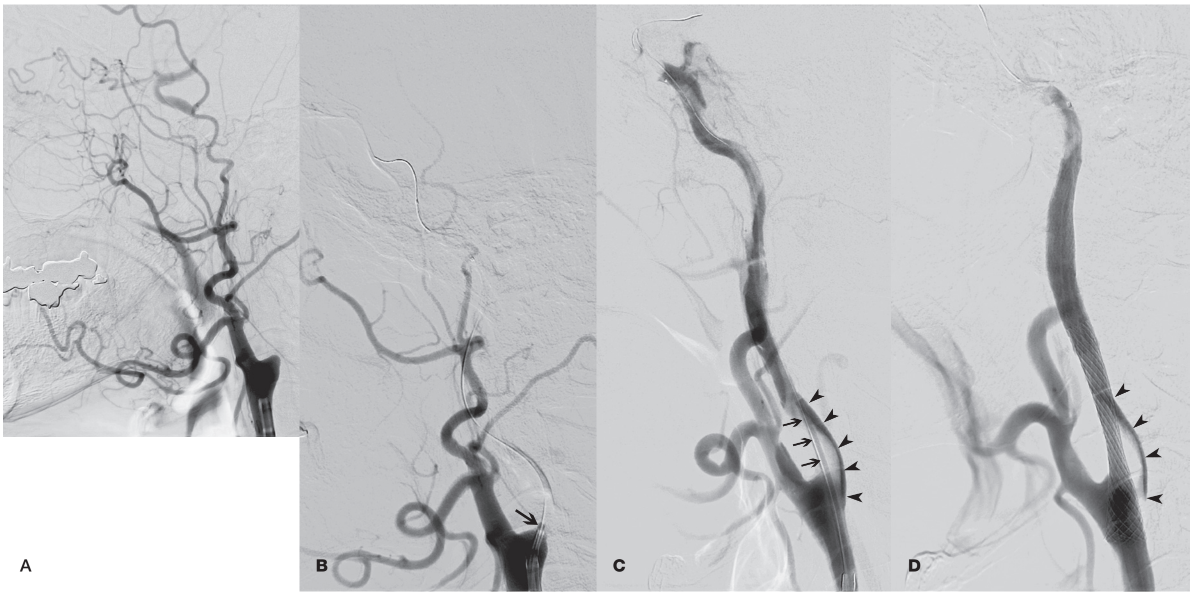

Figure 2 A) Right common carotid artery angiogram in lateral view shows occlusion of the internal carotid artery (ICA) at the origin. Note retrograde opacification of the distal ICA from external carotid artery collaterals. B) The occluded stump is penetrated from the posterior side (arrow). C) Interim angiogram demonstrates contrast stasis at the posterior wall (arrowheads) identical to the course of the initial guidewire penetration (B). Note guidewire migration to the anterior side of the ICA wall (arrows). D) Post-stenting angiogram demonstrates persistent stasis of contrast in the posterior wall of the ICA. Stents are located anterior to the stasis of contrast. Contrast filling defect in the anterior ICA wall seen in C) may represent dissection created by angioplasty, which is now not visible by apposition to the arterial wall by the stents.

distal to its origin (Figure 3A), and the patient underwent endovascular revascularization two months later after double antiplatelet therapy was initiated. Initially, the posterior side of the stump was targeted to penetrate the occluded segment. Multiple attempts to penetrate through the occluded segment were unsuccessful (Figure 3B), and therefore the target was changed to the anterior side of the stump. This resulted in successful advancement of the devices to the cavernous portion of the ICA (Figure 3C). However, following attempts failed to secure distal ICA true arterial lumen, and the procedure was aborted. We postulate that the procedure was unsuccessful not because of failure to select the "true lumen", but due to presence of thick fibrin cap at the distal ICA stump. Interestingly, as in patient 3, persistent stasis of contrast is seen in the posterior side of the ICA wall at the end of the procedure (Figure 3D).

Discussion

For revascularizing occluded vessels, one has to assume an imaginary "true lumen" in which to direct guidewires and catheters, as no "roadmap" is present to assist in advancing devices. A "true lumen" is a theoretical tract of what had been the arterial lumen before vessel occlusion that should guide and facilitate device advancement upon entering it. From our experience of revascularizing 11 ICA subacute and chronic occlusions, we postulated that initial penetration of the occluded stump from the anterior side will provide maximal chance to access the "true lumen". This strategy was derived from our observational findings during procedures, and from consideration of the anatomical extension pattern of carotid plaques. To the best of our knowledge, this is the first report to discuss the strategy to revascularize the occluded carotid artery in relation to the anatomy of the carotid plaque.

Atherosclerotic lesions have been demonstrated to propagate at the outer walls of vessel bifurcations and points of blood flow recirculations and stasis [12,14]. The posterior wall of the carotid artery bifurcation is known as such geometrically predisposed location for atherogenesis [12,14-16]. Low or oscillatory shear stress at this site is believed to mediate endothelial responses such as increased cell cycling, cell adhesion, production of vasoconstrictors, vulner-

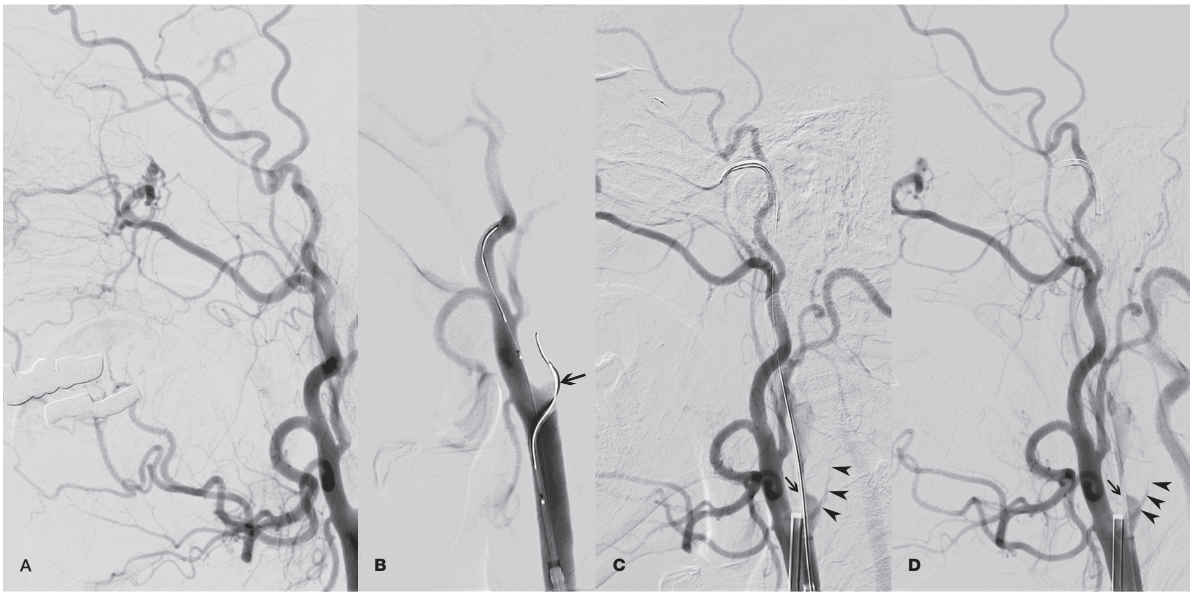

Figure 3 A) Right common carotid artery angiogram in lateral view shows occlusion of the internal carotid artery (ICA) 1 cm distal to its origin. B) Arrow indicates initial guidewire penetration from the posterior side of the occluded stump. C) Following multiple unsuccessful attempts to penetrate the occluded segment from the posterior side, the anterior side of the stump is re-penetrated (arrow) with successful guidewire advancement. Note stasis of contrast in the posterior wall of ICA (arrow heads). D) Failure to penetrate distal ICA stump resulted in an aborted procedure. Persistent stasis of contrast is seen in the posterior wall of ICA at the end of the intervention (arrowheads).

ability to apoptotic stimuli, leading to an atherogenic endothelial phenotype [12]. In clinical practice, angiograms of carotid artery stenosis often show localized narrowing extending anteriorly from the posterior wall with preservation of vessel lumen near the anterior wall (Figure 4). Indeed, in the report of Zarins et al., analysis of carotid endarterectomy pathological specimens showed greatest plaque thickness in the posterior wall of the carotid bifurcation [11]. Based on these facts, we hypothesized that in chronically occluded cervical ICA, entry to the "true lumen" should be located near the anterior wall of the stump of occlusion, and initial selection of this lumen could facilitate crossing the occluded ICA segment. Indeed, less difficulty in advancing guidewires through the occluded segment was more common in the anterior penetration group compared to the posterior group (6/7, 86% versus 1/4, 25%, respectively) supporting our hypothesis.

Another interesting observation was that there was high rate of guidewire migration to the anterior side of the ICA with contrast stasis at the posterior ICA wall in the posterior penetration group (3/4, 75%). This may have resulted from the tendency of the stiff devices to migrate into a space of less resistance, indicating that a more potent lumen for revascularization exists in the anterior side than in the posterior. In the case of patient 3, in whom the stump was accessed from the posterior side, penetration of the stump itself was extremely difficult. This approach was selected because the posterior side of the stump showed more cranial extension on angiogram. Although the guidewire initially crossed the lesion from the posterior side, angiograms after guidewire/catheter penetration and stent placement revealed that the devices were positioned anterior to where the guidewire had initially passed (Figure 2B-D). In addition, stagnation of contrast material was seen in the posterior wall outside the stent. We speculate that the devices had migrated to a more "favorable" lumen that had once been the true arterial lumen. In the case of patient 4, the stump was initially accessed from the posterior side with failure to penetrate the occluded segment, leading to change in the target to the anterior side of the stump. This approach allowed easy advancement of the guidewire as far as to the cavernous ICA. Interestingly, as in the case of patient

3, stasis of contrast was observed in the posterior side of the arterial wall (Figure 3C,D). Revascularization was unsuccessful because of failure to penetrate the distal ICA stump. Findings in patients 3 and 4 further support our hypothesis that anterior penetration with initial entering in the "true lumen" is important to revascularize occluded ICAs.

In our series of revascularizing ICA subacute and chronic occlusions, success rate in revascularization did not differ in the anterior or posterior penetration groups (5/7, 71% versus 3/4, 75%, respectively). However, taking into account the two cases in the posterior penetration group in which the devices migrated to the anterior side as the anterior penetration group (cases 3 and 10), the success rate of the anterior penetration group was 7/9, 78%, whereas that of posterior penetration group was 1/2, 50%. Three cases failed revascularization, two due to unsuccessful penetration of the distal ICA stump, and one due to inability to penetrate the occluded segment. In the two cases of unsuccessful distal ICA stump penetration, the guidewire at least crossed the cervical ICA occluded segment as far as the intracranial ICA. One case was performed with anterior penetration (case 6), and the other was posterior penetration transferred to anterior (case 4). As far as the subject was limited to crossing the cervical occluded segment, anterior penetration and its variant (posterior to anterior transfer) yielded a high success rate of 82% (9/11).

To improve the results of revascularizing occluded ICA, a more reliable method is needed to navigate guidewires through the distal ICA occluded stump. In our experience, once occlusion at the ICA origin had been successfully crossed, the next difficulty lay in navigating a guidewire across the acute curve at the petrous ICA. This is because the curve diverts pushing and torque force, leading the guidewire to run near the periphery of the vessel lumen. This often causes dissection. Few reports describe the technique of penetrating the occluded segment in the ICA. Kao et al., in their large series of revascularizing occluded carotid artery, used 0.014-inch coronary microguidewire with a penetrate-and-advance fashion, avoiding unnecessary rotation or drilling motion [6]. We agree with this strategy, since forceful guidewire manipulation further drives the device peripherally.

In revascularizing occluded subclavian arteries, Henry et al. employed 0.035-inch hydrophilic guidewires using controlled force [17]. The cardiovascular literature has numerous reports on the technique of revascularizing chronically occluded vessels that may be applied in the carotid artery context. These include vibration angioplasty [17], application of excimer laser beam through a guidewire [19], guidewire utilizing optical coherence reflectometry and radiofrequency ablation [20], paral-

Figure 4 Right common carotid artery angiogram in lateral view in a 77-year-old patient presenting with transient ischemic attack. Severe stenosis is seen at the carotid artery bifurcation. Note the plaque extending from the posterior wall with preservation of vessel lumen near the anterior wall (arrows).

lel-wire method [21], "see-saw" wiring method [22], and retrograde approach [23]. The larger diameter of the carotid artery may allow the use of angioscopy to guide penetration of the occluded segment. This approach may enhance the understanding of the pathology of the occluded segment. However, more experience, improvement of devices, and development of new technologies are required to establish the optimal strategy to revascularize occluded cervical ICAs.

Conclusion

In our small series of revascularizing ICA subacute and chronic occlusion, initial targeting of the anterior side of occluded stumps resulted in favorable results by facilitating guidewire penetration of cervical ICA occluded segment. This may be related to the posterior to anterior plaque progression at the common carotid artery bifurcation. Further studies are needed to clarify this hypothesis.

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